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LCP-10 INTELLIGIBILITY OF OXYGEN MASKS AND MICROPHONES IN AIRCRAFT NOISE

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

James W. Brinkley

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Acting Director
Biodynamics & Bioengineering Division
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A series of studies was conducted to examine the effectiveness and limitations of the Joint Tactical Information Distribution System (JTIDS) voice channel in noisy environments. Initial efforts to improve performance focused on the input to JTIDS, specifically modifications to the oxygen mask and the use of prototype noise cancelling microphones. No improvements in voice communications were observed with the modified masks, prototype microphones or the various mask-microphone combinations. These and other measurement data demonstrated that the limit to voice communications performance with this system in noise was imposed at the listener instead of at the talker (oxygen mask input). The sound attenuation properties of the helmets and headsets were not adequate to provide the required speech-to-noise ratios at the ear in the highest noise levels. Among the

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conclusions were (1) speech processed by the JTIDS voice channel may be more vulnerable to noise or easier to mask than regular speech, (2) efforts to improve voice communications effectiveness in noise in the near term should focus on improvements in the signal at the listener and (3) active noise reduction technology in headsets has been proven, it offers a high potential for enhanced voice communications with the basic JTIDS voice channel and its utility should be pursued. Keywords: F-15 aircraft, [illegible]

PREFACE

This work was accomplished in the Biological Acoustics Branch, Biodynamics and Bioengineering Division, Armstrong Aerospace Medical Research Laboratory, Human Systems Division, Air Force Systems Command. This effort was accomplished under Task 723121, Biocommunications, Work Unit 72312104, Bioacoustics and Biocommunications Research. The Task Manager for this effort was Richard L. McKinley, AAMRL/BBA.

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LPC-10 INTELLIGIBILITY OF OXYGEN MASKS AND MICROPHONES IN AIRCRAFT NOISE

BACKGROUND

The voice communications effectiveness of the Joint Tactical Information Distribution System (JTIDS) LPC-10 voice channel has been an important facet of a larger ongoing in-house research task on Digital Audio Technology for Aircraft (DATA). DATA is concerned with the development and integration of new technologies into a new, digital aircraft intercommunications system. The JTIDS research is focused on the quantification and enhancement of the voice communications capabilities of that tactical information distribution system voice channel.

Early work on the performance of the JTIDS voice channel in quiet was accomplished in the laboratory at Rome Air Development Center (RADC) East. In-flight problems with the system were attacked by the Lincoln Laboratory (LL) at Massachusetts Institute of Technology (MIT) in Cambridge, MA. The developmental effort at MIT focused on improvements in the coding and produced a LL High Quality Linear Predictive Coder (LPC) and a LL Standard Enhanced LPC-10 unit. The efforts at the Armstrong Aerospace Medical Research Laboratory (AAMRL) have focused on improvements in the acoustic features of the voice channel and of the personal equipment worn by the flight crew.

The JTIDS research activities at the AAMRL have included two main phases consisting of (a) a real time data link involving voice communications among experienced air crew members and (b) the measurement of voice communications effectiveness under controlled laboratory conditions. The data link consists of an E3A operator communications station at Lincoln Laboratory connected by a dial-up telephone line to an F-15 pilot communication station at the AAMRL Biocommunications Laboratory, Dayton, Ohio (Figure 1). The communications link includes the Department of Defense (DOD) standard 2400 bit per second (bps) JTIDS class 2 voice channel. Experienced E3A crew members at Lincoln Laboratory communicate with experienced F-15 pilots at the Biocommunications Laboratory using typical operational voice exchanges that occur during sweep, lane defense and E3A threat awareness scenarios. The relatively low level noise environment of the E3A is simulated at the Lincoln Laboratory station and the more intense noise environment of the F-15 cockpit is simulated at the Biocommunications Laboratory. Data on the speech intelligibility during these test sessions, as measured by the Diagnostic Rhyme Test

(DRT)[1], indicated that the mode of voice communications between the E3A in quiet and the F-15 in noise appeared to be acceptable[2].

The laboratory investigations measured the speech intelligibility of the F-15 pilot to the F-15 pilot. Ten experimental subjects trained to a level of communication performance equal to that of the F-15 pilots were used in these studies. Both talkers and listeners wore the Air Force standard HGU-26/P flight helmet and the MBU-12/P low profile oxygen mask. Both talkers and listeners were in the simulated F-15 cockpit noise environment at four different sound pressure levels ranging from quiet to 115 dB SPL (re 20 uPa). These measurements were made with the basic aircraft intercommunication system and with the JTIDS vocoder installed in the communications link. Details of the experimental procedures and laboratory facilities are described in the sections that follow on Method, Experimental Equipment and Experimental Procedure.

Four factors are visible in the results of these measurements which are summarized in Figure 2. (1) Voice communications were progressively degraded as the levels of the noise environments increased. (2) Speech intelligibility for the basic aircraft communication system was about 12% to 14% less in the highest noise condition than in the ambient condition of about 75 dB. However, the voice communications remained above 80% correct intelligibility and acceptable even with the reduction. (3) The intelligibility of the aircraft intercommunication system with the addition of the vocoder to the link was degraded under all conditions. The reduction in intelligibility attributed to the vocoder was significant and amounted to a loss of about 15% to 25% in addition to that caused by the noise. (4) An appraisal of the expected communications with the vocoder in the operational situation based on AAMRL performance criteria (section on Performance Criteria) indicated marginal to unacceptable communications in the two higher noise environments with scores below the 80% correct response level.

INTRODUCTION

Voice communications were marginal to unacceptable for personnel in relatively high levels of noise using the standard MBU-12/P oxygen mask with the M-101 noise-cancelling microphone and the JTIDS voice system. The oxygen mask was targeted as the probable source of this communications problem because of observations and narrative reports of interfering noise in the mask from respiration and the inhalation/exhalation valves as well as noise from outside sources entering the mask. It was reasoned that these noises entered the communications system at the input, were processed along with the speech signal by the 2400 bps class 2 voice channel and were involved in voiced-unvoiced errors, decision errors and pitch tracking errors. A better speech-to-noise ratio inside the mask at the input to the system would be expected to reduce these errors and restore a portion of the lost or lowered intelligibility. An effort was initiated to examine the speech input effectiveness of the oxygen mask system when used with the vocoder in noise. An analysis indicated that an increase of only about 5% to 10% in intelligibility in these borderline, high level noise situations would result in acceptable voice communications.

This investigative effort focused on modifications of the oxygen mask as a primary means of achieving the desired improvement in voice communications. The proposed modifications to the mask included an overall reconfiguration to provide larger and smaller volume masks, the use of separate inhalation and exhalation valves positioned further away from the microphone, a greater density hard shell, absorbant acoustic material lining the mask interior, oxygen mask hose materials with higher sound attenuation properties, and others. Initially, two approaches were implemented for study, (1) the hard shell of the mask was reconfigured to provide some masks that were smaller and some that were larger in volume than the MBU-12/P mask and (2) the standard respiration valve was reconfigured so that the inhalation valve was positioned to the right of the microphone and the exhalation valve was positioned to the left of the microphone. These modifications provided two large volume (LV) masks and two small volume (SV) masks with respiration valves repositioned from the center to the sides of the mask. The voice communications performance of the modified masks was compared to that of the standard MBU-12/P oxygen mask.

GOALS

The primary objective of this series of studies was to identify which configuration of oxygen mask provided the best speech communications with the vocoder in noise. During these studies two prototype noise cancelling microphones that were designed for use in oxygen masks were also evaluated in the various masks. An additional objective was to identify the mask-microphone combination that provided the best voice communications performance with the communication system. The standard MBU-12/P mask and noise-cancelling M-101 microphone were included in all studies as the performance baseline or standard. It was expected that the modified masks or mask-microphone combinations might provide performance superior to that of the standard equipment to the extent needed to achieve the desired increase in intelligibility with the JTIDS system.

APPROACH

All studies were accomplished in the Biocommunications Research Laboratory utilizing a facility which simultaneously measures the speech communication performance of ten trained subjects. The experienced subjects acted as talkers and as listeners while wearing the various oxygen mask-microphone combinations in different levels of an operational acoustic noise environment. The experimental conditions and the items of personal equipment were varied to reveal the effects of the noise exposures on the talker, on the listeners and simultaneously on talker and listeners. These combinations of conditions were designed to reveal differences in word intelligibility among the systems evaluated as well as possible sources of the differences. In all studies the talkers wore the Air Force Standard HGU-26/P flight helmet and the various modified oxygen masks which provided breathing air. The basic experimental methodology remained unchanged during all studies except for the number of talkers which was usually ten but as few as four for particular measures.

EXPERIMENTAL DESIGN

Average percent correct intelligibility of the Modified Rhyme Test (MRT)[3], adjusted for guessing, was the criterion measure. The independent variables were oxygen mask, oxygen mask/microphone configuration, noise conditions, experimental microphones, listening with a headset vs a helmet and individual talker and listener noise environments. The dependent variable was percent correct speech intelligibility of the communicators. Experienced talkers presented the speech materials to experienced listeners. The main experimental variables examined in these studies are shown in Table 1.

Talkers wore the various mask-microphone combinations and the HGU-26/P flight helmet which operated through the AF standard aircraft intercommunication system and JTIDS LPC-10 vocoder with the standard government algorithm. Listeners wore the standard H-157A in-flight headset or the HGU-26/P flight helmet. Data were collected according to the requirements of the individual studies which always included the JTIDS vocoder in the systems and the noise conditions. Data were treated by measures of variance, central tendency and on occasion, Analysis of Variance.

METHOD

Subjects

These investigations utilized volunteer subjects (females and males) who were highly experienced in voice communications effectiveness research. All were recruited from the general civilian population and were paid an hourly rate for their participation. All were normal hearing subjects with hearing threshold levels no greater than 15 dB at the standard audiometric test frequencies of 500 Hz to 6000 Hz. Subjects were fully trained on the requirements of these studies prior to data collection.

All subjects spoke mid-western American speech and none exhibited a noticeable accent, dialect or speech problem. All subjects, both male and female, participated as talkers and as listeners.

Facility

The Voice Communication Research and Evaluation System (VOCRES) was utilized for this study[4]. This system is located in a large reverberation chamber and it contains the operator, system and environmental variables known to most directly affect voice communications effectiveness. VOCRES consists of a central processing unit that controls the experimental sessions and ten individual communication stations. Each station is equipped with an alphanumeric light emitting diode (LED) display, a subject response unit consisting of special keyboards for entering performance responses to the central processor, and a large volume unit meter (Volume Unit) that indicates voice level of the speech produced by the talker at that station. Each station also contains the Air Force standard AIC-25 aircraft intercommunication system, voice communications headgear, and air respiration system with an A-14 diluter demand regulator, an AF standard oxygen mask and either an HGU-26/P flight helmet or an H-157A communications headset.

A portable VOCRES individual communications station was installed in a second reverberation test chamber and used for those experimental conditions in which the talker and listeners were in different acoustic environments.

The central processing unit provides real time stimulus display, response measurement, subject performance display to the operator, data collection and data treatment in terms of measures of variance and central tendency. Programmable high intensity sound systems emulated the operational environments used in the study in each of the two acoustic test chambers.

High Intensity Sound System

The VOCRES chamber and the second acoustic test chamber contain programmable high intensity sound systems that permit the accurate reproduction in the laboratory of ambient and environmental noise conditions of a wide variety of operational situations. This investigation was accomplished in the presence of a generic tactical fighter aircraft cockpit noise at four intensity levels; ambient or about 75 dB, 95 dB, 105 dB and 115 dB re 20uPa. The spectrum of the noise is displayed in Table 2. The various mask-microphone configurations were evaluated in the noise conditions shown in Table 1.

Intelligibility Test Materials

Speech intelligibility was measured in this study using the standard word intelligibility test, the Modified Rhyme Test. The MRT is considered the test of choice for evaluating the performance of military communications systems and equipment. The materials consist of word lists that are essentially equivalent in intelligibility, with each list comprised of 50 one-syllable words. During this study the talker spoke a test word embedded in the carrier phrase, "Number______, you will mark _________, please." The listeners then selected from a set of six words displayed at the individual stations, that word that was believed to have been spoken by the talker. The intelligibility score for that word list was the average percent correct for the number of listeners participating in the study. The scores were adjusted for correct answers obtained by guessing (2.4 X Number Correct - 20) expressed as percent correct. The MRT is easy to administer, score and evaluate and it does not require extensive training of the subjects.

EXPERIMENTAL EQUIPMENT

Oxygen Masks

Experimental oxygen masks were fabricated with two modifications intended to improve word intelligibility performance in noise. One modification focused on internal mask volume and experimental units were independently constructed by two different contractors. One unit enclosed a smaller volume (SV, Figure 3-B and D) and the other enclosed a larger volume (LV, Figure 3-A and C) than that of the MBU-12/P oxygen mask.

The second modification involved separation and reconfiguration of the respiration valve so that the inhalation valve was located to the right of the microphone and the exhalation valve was positioned to its left. This modification in one of the masks can be seen in Figure 4.

Experimental Microphones

Two prototype microphones were evaluated in the experimental and standard oxygen masks during this series of studies. One microphone was a modification of the AF standard M-101 that reduced the thickness of the unit by about 50%. The second microphone was a totally new configuration dual-array noise cancelling microphone. All microphones were fully compatible with the AN-AIC/25 intercommunications system. The configuration of the dual array microphone (two elements) is displayed in Figure 5 adjacent to th M-101 unit. The top view of the modified M-101 appears the same as the M-101 microphone.

PERFORMANCE CRITERIA

Voice communications performance of equipments evaluated in this laboratory (in the VOCRES facility) over many years using the MRT has been very similar to that subsequently experienced in the operational situation. Consequently, a set of guidelines or criterion measures based on our laboratory data has been adopted as an estimator or predictor of expected communications performance in the operational situation. Systems and components displaying an intelligibility performance of 70% correct and below are generally unacceptable for operational applications. Those with performance in the range from 70% to 80% are considered marginal and their success in the field depends upon the specific conditions under which they are implemented. Equipments exhibiting intelligibility performance at about 80% and above are considered fully acceptable under operational conditions. The various mask-microphone configurations in this study were examined in terms of these guidelines.

EXPERIMENTAL PROCEDURE

The mask-microphone combinations were investigated under the various conditions described earlier, including four different levels of aircraft cockpit noise. All subjects were custom fit with the appropriate size oxygen mask and HGU-26/P flight helmet. Talkers wore the HGU-26/P helmet and the listeners wore either the HGU-26/P flight helmets or the H-157A in-flight headsets. Both the talker and the listeners were in the same test chamber for the early studies in this series. The talker sat at a single portable VOCRES station in the second acoustic test chamber and the listeners sat at the ten stations in the VOCRES facility for some of the later studies. The talker's speech was processed through Air Force intercommunications systems, ARC-164 aircraft radios and JTIDS vocoders with the Department of Defense standard LPC-10 algorithm (Figure 6).

A Round Robin paradigm was utilized in which subjects participated both as talkers and as listeners in all conditions. Each subject in the VOCRES acoustic chamber performed as the talker while all others participated as listeners. When studies were conducted using two acoustic chambers, the talker spoke in the second acoustic chamber and the listeners responded in the VOCRES chamber. The order of presentation of these conditions was random.

Presentation of each word list required about five minutes. About twenty word lists were completed during each daily session. Following training, performance measurements were obtained to satisfy the requirements of the particular study. Data were treated by measures of variance and central tendency.

EXPERIMENTAL STUDIES

MODIFIED OXYGEN MASK PERFORMANCE

The initial study was designed to measure the speech communications performance of the modified oxygen masks relative to the standard MBU-12/P mask in the noise environments. The two SV and the two LV masks were fit with the M-101 noise cancelling microphone (The A and B designators refer to units provided by Contractor A and Contractor B). Subjects were selected to obtain a good fit with the prototype masks when worn with the AF flight helmet. Ten talkers presented the speech materials in the round robin paradigm used in these tests in each of the four noise conditions.

Results of these and other measurements in which the prototype masks were used reveal very small differences in intelligibility that could be attributed to the masks (Figure 7). The range of scores for the ambient condition is only 2% and for the most intense noise condition it is only 4%. On the basis of these data, there is no consistent, significant improvement in speech communications effectiveness that can be attributed to the modified masks. In addition, none of the modified masks displayed overall better performance than that obtained for the standard MBU-12/P mask.

MODIFIED OXYGEN MASK-PROTOTYPE MICROPHONE PERFORMANCE

Two prototype noise cancelling microphones were designed for use in the oxygen mask. The speech intelligibility performance of these units and the M-101 microphone were measured when they were mounted in the four modified oxygen masks as well as the MBU-12/P mask in the noise conditions. Five talkers (three male and two female) and ten listeners participated in these measurements. The intelligibility performance among the three microphones was very similar. The average intelligibility data for these microphones in the 12/P mask and across all five oxygen masks are summarized in Figures 8(a) and 8(b).

Overall, the performance of the standard M-101 microphone was better than that of the other units in both sets of data even though the respective scores were relatively close. The poor performance of the array microphone is attributed to relatively low scores obtained when it was mounted in one of the LV masks. Variations in speech intelligibility among the various mask configurations were again very small, reflecting differences of about the same magnitude as reported in Figure 7. These data revealed no speech intelligibility advantages of the two prototype microphones over the standard unit in the different oxygen masks. No significant improvements were observed in the performance of any of the masks when used with the prototype microphone units.

PERFORMANCE WITH "GOOD" AND "BEST" FIT OXYGEN MASKS

The modified oxygen masks (all LV's and SV's) were fabricated in only the "average" size. Subjects were selected to "fit" this one size, however some had facial shapes and dimensions that allowed a "good" fit but not a "best" fit with the masks. Poor fitting masks may have acoustic leaks that allow noise to enter the system at the microphone and reduce communications effectiveness. The average performance of those subjects who were "best" fit was compared to that of the total listening panel to determine if such acoustic masking was present with the "good" fit devices. The total panel consisted of ten subjects which included the four subjects who were "best" fit.

The speech intelligibility measured on four subjects who obtained "best" fits with the oxygen masks is compared to that obtained on the panel of ten subjects ("average") in Figure 9. Two sets of data for "best" and "average" fit are shown in Figure 9 with one set representing the speech intelligibility averaged over all of the oxygen masks for both groups of subjects in the four noise conditions. The other set of data is for the same conditions with the MBU-12/P mask only and is included for comparison.

The speech intelligibility of subjects who were "best" fit ranges from 5% to 10% higher than that measured for the total panel. The progressive degradation that accompanies increasing levels of the noise is greater for the "average" than for the "best" fit. This observation is present in the MBU-12/P data as well as the overall average data. The differences are significant at the two high noise level conditions. Typically in these types of speech intelligibility data in noise with trained subjects, variations of about 5% to 8% or more are statistically significant.

The average speech intelligibility performance that might be expected in the operational situation with these equipments would be closer to the "best" fit than the "good" fit. Although the experienced air crew member typically has a "best" fit, less than "best" fits do occur. These data verify the general requirement for a very good fitting mask and indicate the magnitude of speech intelligibility losses that can be attributed to a poorly fit mask.

TALKER/LISTENER IN QUIET/NOISE

The data from the first series of studies identified no oxygen mask modification, prototype noise cancelling microphone or combination of these equipments that provided a significant improvement in performance over that of the AF standard oxygen mask and microphone. Further analyses suggested that the potential improvements in communications due to the changes in the oxygen mask may have been masked by the noise environment at the listener. Additional studies were accomplished in which the acoustic environments at the talker and at the listeners were independently controlled to further examine this possibility.

The MBU-12/P and two SV modified masks were examined with the M-101 and the modified M-101 microphones. Although the relative performance of the LV masks was similar to that of the other masks their large size and shape interfered with the vision of the wearer and they were judged to be unacceptable. The LV masks were deleted from further consideration.

The voice communications system was modified from that used in the earlier studies (Figure 6). An amplifier which provided additional gain for the vocoder output-intercommunications system input signal was removed from the communications link to better emulate the operational situation. This amplifier is not a part of the standard aircraft intercommunication system but may have subsequently been added to these systems in operational aircraft to improve voice communications with the vocoder in the high levels of noise. The amount of gain available to the listener's headsets without the amplifier was less than for the earlier studies and this was reflected in the lower values of the performance in noise data.

The primary independent variable in this talker-listener noise environment study was the level of the noise at the talker relative to the level of noise at the listener. Intelligibility was measured with both the talker and listener in quiet (TQLQ), the talker in noise and the listener in quiet (TNLQ), the talker in quiet and the listener in noise (TQLN) and both the talker and listener in noise (TNLN). The noise exposure for both the talker and listener emulated the spectrum of the high performance tactical aircraft cockpit at the levels of about 75 dB, 95 dB, 105 dB and 115 dB, as before.

The percent correct word intelligibility of the mask-microphone combinations collapsed across the other conditions confirm the earlier findings (Figure 10).

Performance among all units was very similar; no mask-microphone combination emerged as a "best" unit and the standard MBU-12/P (with M-101) displayed the highest score even though the range of these main effect means was only 4%. Neither the main effects nor the earlier data on performance justify replacement of the standard items with any of these units.

The overall effectiveness of voice communications for the talker-listener measures is shown collapsed across mask-microphones in Figure 11. The word intelligibility scores for all the TQ/LQ conditions were essentially identical as expected. Intelligibility decreased about 4% to 10% when the talker went from quiet to the noise environments with the listener remaining in quiet. However, the major reductions in intelligibility were observed when the listener was in the noise whether the talker was in quiet or noise. Reductions in intelligibility of about 30% in the 105 dB noise and 60% in the 115 dB noise for the TQ/LN are attributed to effects on the listener, since the talker is in quiet.

The TQ/LN and TN/LN sets of data differ little from one another with slightly better performance with the talker in noise (TN/LN). Although not universal, it is also not uncommon to observe communications that are better when the talker is in noise than in quiet for situations that are otherwise very similar. Factors such as the masking effect of the noise on the sidetone of the talker and a perceived increase in difficulty for the listener result in an increased effort to communicate by the talker and in a higher level of understanding by the listener. This is much more common in the higher levels of noise. Overall, these sets of data clearly demonstrate that the degradation of speech communication performance occurs at the listener.

The intelligibility scores in this study are quite low for the conditions in the higher levels of noise. The reader is reminded that an amplifier that boosted the vocoder output-intercommunication system input had been removed from the communications system for this study. This affected the speech signal at the listener's stations limiting the maximum gain to a level relatively lower than that available in the other studies in this series. The poor signal to noise ratios at the ears of the subjects are reflected in the low intelligibility scores in the 105 dB and 115 dB noise conditions.

LISTENER PERFORMANCE WITH THE HGU-26/P AND THE H-157A

Verification was obtained that the voice communications problem was caused primarily by the noise during the listening phase of the communications. The source of the problem was identified as the performance limitations of the helmet/headset personal equipment worn by the listener to provide a voice communications capability and prevent both harmful and interfering effects of noise. The most common equipments worn by Air Force personnel in these environs are the HGU-26/P flight helmet and the H-157A communications headset. A final study in this series was conducted to determine the relative effectiveness of these standard units in noise.

This study measured the intelligibility of the talkers and/or listeners in the four noise environments. Talkers wore the HGU-26/P flight helmet and the listeners wore either the flight helmet or the H-157A communications headset. Ten talkers and listeners participated in this study and the listeners did not wear oxygen masks. The vocoder output-intercommunication system input amplifier removed for the talker/listener in noise study was replaced for this study allowing the subjects to obtain adequate gain from their listening stations.

The majority of the subjects obtained a good fit with the oxygen mask while only four obtained a "best" fit during the talking phase of the study. The resulting mean scores were slightly lower than would have been obtained with all "best" fit subjects. Nevertheless, the relative performance of the helmet and headset was not influenced by this factor because talking conditions were identical for both the listening conditions.

The overall intelligibility obtained was quite similar for the two communications units (Figures 12 and 13). Performance was essentially identical for the ambient conditions and decreased with increasing levels for the noise conditions. The mean data indicates only slightly higher scores for the listeners with the helmets over those with the headsets. This similarity in performance is understandable. The ear enclosures in helmets determine the overall sound attenuation and those of the HGU-26/P provide similar attenuation to the H-157A earcups.

These data show the communications effectiveness to be about the same for the headset and the helmet. However, listeners did not wear oxygen masks with the flight helmets which would have resulted in a little higher intelligibility scores than for the headset conditions. The oxygen masks require a tight fit against the face which pulls the helmet earcups against the head providing a better acoustic fit.

SUMMARY

This report describes a series of studies conducted to examine the effectiveness of tactical voice communications with the JTIDS LPC-10 voice system in noisy environments. Initial efforts focused on increased communications effectiveness to be obtained by improvements in oxygen mask system characteristics. The MBU-12/P low profile oxygen mask was modified by reconfiguration of the hard shells and relocation of the respiration valves. Modified masks were fabricated with internal volumes that were larger and smaller than that of the MBU-12/P. The respiration valves were repositioned with the inhalation valve to the right and the exhalation valve to the left of the centered M-101 microphone.

The initial study of mask intelligibility revealed no consistent, significant improvement in intelligibility attributed to the prototype masks and none performed better than the standard MBU-12/P. A second study which examined the modified masks installed with prototype noise cancelling microphones revealed no significant improvements in the mask-microphone combinations over the AF standard system. The best performance was obtained with the standard MBU-12/P mask and the M-101 microphone. The small number of prototype masks did not cover the full range of sizes, allowing only about 40% of the subjects to be "best" fit and the remaining 60% "good" fit. A third study showed the intelligibility of the "best" fit devices to be 5% to 10% better than the "good" fit devices.

Data from the mask modification and mask-microphone studies showed no improvement in performance but did suggest that the noise at the listener was the major factor degrading communications effectiveness. A study of the talker and/or the listener in quiet and/or noise using the mask-microphone combinations confirmed the earlier findings of no significant improvements due to the prototype systems. The major finding demonstrated relatively small effects of the noise at the talker (oxygen mask) and substantial reductions due to the noise at the listener. Improvements in intelligibility that might have been provided by the modified oxygen mask and prototype microphone systems could not be seen because of the large masking effects of the noise observed at the listener.

The features required for successful voice communication in noise are well understood. The primary characteristics of the speech signals are positive speech-to-noise ratios and acceptable quality at both the talker and the listener. The basic JTIDS LPC-10 system examined in these studies (Figure 6) appears to be satisfactory in quiet and the low level noise and marginal to unacceptable in the two higher level noise environments. The major impact of the noise was not on the talkers but on the listeners and is attributed to the inadequate noise excluding features of the headsets and helmets worn by the subjects.

The noise excluding properties of headsets and helmets are determined by the physical characteristics of the ear enclosures or earcups and their coupling to the head. Increased noise exclusion can be provided, however features such as the size and mass of the earcups and the force with which they are held against the head must be greater than with current items. Experience has shown that the larger, heavier and more uncomfortable units that provide greater attenuation will not be worn even at the risk of adverse effects of the noise. No new advances or breakthroughs have been experienced with passive earcup attenuation in the past three decades. Current system designs are compromises which provide as much protection as is reasonable with acceptable wearability features.

The technology of Active Noise Reduction (ANR) has been successfully implemented in a joint effort with the Biocommunications Laboratory and the BOSE Corporation[5]. This achievement is a significant breakthrough in the performance of communications headsets in noise that combines both passive and active sound attenuation. A new headset earcup has been designed with improved wearability and comfort features (Figure 14). The ANR unit effectively reduces large portions of the acoustic energy below 1500 Hz through electronic-acoustic cancellation. The amount of active noise cancellation is additive to the passive attenuation provided by the ear enclosures. Development of these units has been completed and they have been transitioned to the Life Support Systems Program Office.

Prototype ANR units were evaluated in a pilot study of the basic voice communications system which included the JTIDS vocoder investigated in these studies. The speech intelligibility of the system was increased in the high level noise by about 5% due to the ANR unit worn by the listeners. The acceptability of the speech communications system was quite high with the ANR because the overall noise at the ear of the listener was reduced by a significant amount. A newly designed, gelatin filled, comfort earcup cushion has also proven highly acceptable to the wearers.

Efforts to improve the voice communications of this system with the vocoder should continue to focus on improved performance of the personal equipments worn by the listener and talker and on improved digital processing of the speech signal, in that order. The ANR technology appears to have the highest potential for near term improvement in communications at the listener. Small improvements in the speech signal either through improved algorithms or techniques such as speech stripping will be unnoticed unless presented to the listener at more favorable and acceptable speech-to-noise ratios.

CONCLUSIONS

On the basis of the studies reported herein it is concluded that

1. The modified oxygen masks provided no improvement in intelligibility over that obtained with the AF standard oxygen mask.

2. The modified oxygen mask-prototype noise cancelling microphone combinations provided no improvement in intelligibility over that of the AF standard oxygen mask-microphone system.

3. The AF standard oxygen mask-microphone was usually the best performer, although performance scores were similar among the various units.

4. Oxygen masks that are "best" fit to the talker may provide as much as 5% to 10% better speech intelligibility than less well fit masks.

5. The noise environment at the listener is the primary factor degrading the speech intelligibility of the communications system with a JTIDS LPC-10 voice channel.

6. Improvements in intelligibility attributable to the modified masks and prototype microphones, if any, are hidden by the magnitude of the communication loss due to noise at the listener.

7. The communications effectiveness in noise is about the same with the listener wearing the HGU-26/P or the H-157A; communications is slightly better with the helmet when it is worn with an oxygen mask.

8. The communications problem at the listener is attributed to the inability of the helmet or headset to exclude a sufficient amount of noise to allow an acceptable speech-to-noise ratio at the ear.

9. LPC-10 speech may be more vulnerable to noise and easier to mask than is regular speech.

10. Efforts to improve voice communications effectiveness in noise should focus on improvement of the communications signal at the listener.

11. Active Noise Reduction technology offers a high potential for improved voice communications with the basic system and its utility should be pursued.

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TABLE 1

MAIN EXPERIMENTAL VARIABLES

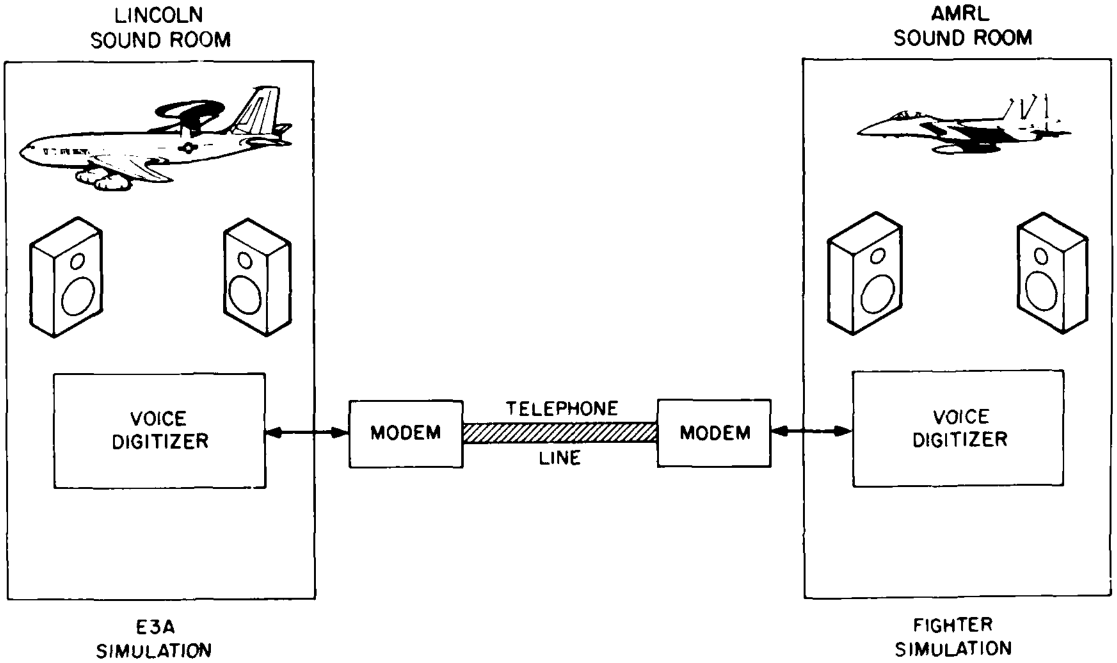
VARIABLE	CONDITIONS
OXYGEN MASK	MBU-12/P; A-LV; A-SV; B-LV; B-SV
MICROPHONE	M-101; MODIFIED M-101; ARRAY
NOISE	AMBIENT (75 dB); 95 dB; 105 dB; 115 dB
FIT OF MASK	"GOOD" FIT; "BEST" FIT
TALKER/LISTENER IN NOISE	TQ/LQ; TN/LQ; TQ/LN; TN/LN
HELMET - HEADSET	HGU-26/P; H-157A

TABLE 2

THIRD OCTAVE BAND SPECTRUM OF GENERIC HIGH PERFORMANCE AIRCRAFT COCKPIT NOISE AT 105 dB OASPL

THIRD OCTAVE BAND CENTER FREQUENCY (Hz)	SOUND PRESSURE LEVEL (dB SPL)	THIRD OCTAVE BAND CENTER FREQUENCY (Hz)	SOUND PRESSURE LEVEL (dB SPL)
25	70.2	630	84.6
31.5	80.4	800	86.2
40	84.1	1000	86.8
50	88.2	1250	88.2
63	95.5	1600	91.0
80	94.9	2000	95.7
100	86.3	2500	97.2
125	98.3	3150	95.7
160	90.3	4000	93.7
200	91.8	5000	91.9
250	89.4	6300	85.6
315	85.3	8000	82.9
400	85.8	10000	79.4
500	84.0	12500	70.5

FIGURE 1. ILLUSTRATION OF THE LINCOLN LABORATORY E3A AND THE AAMRL TACTICAL FIGHTER COMMUNICATION STATIONS DATA LINK OVER WHICH OPERATIONAL VOICE COMMUNICATIONS SCENARIOS WERE EXAMINED



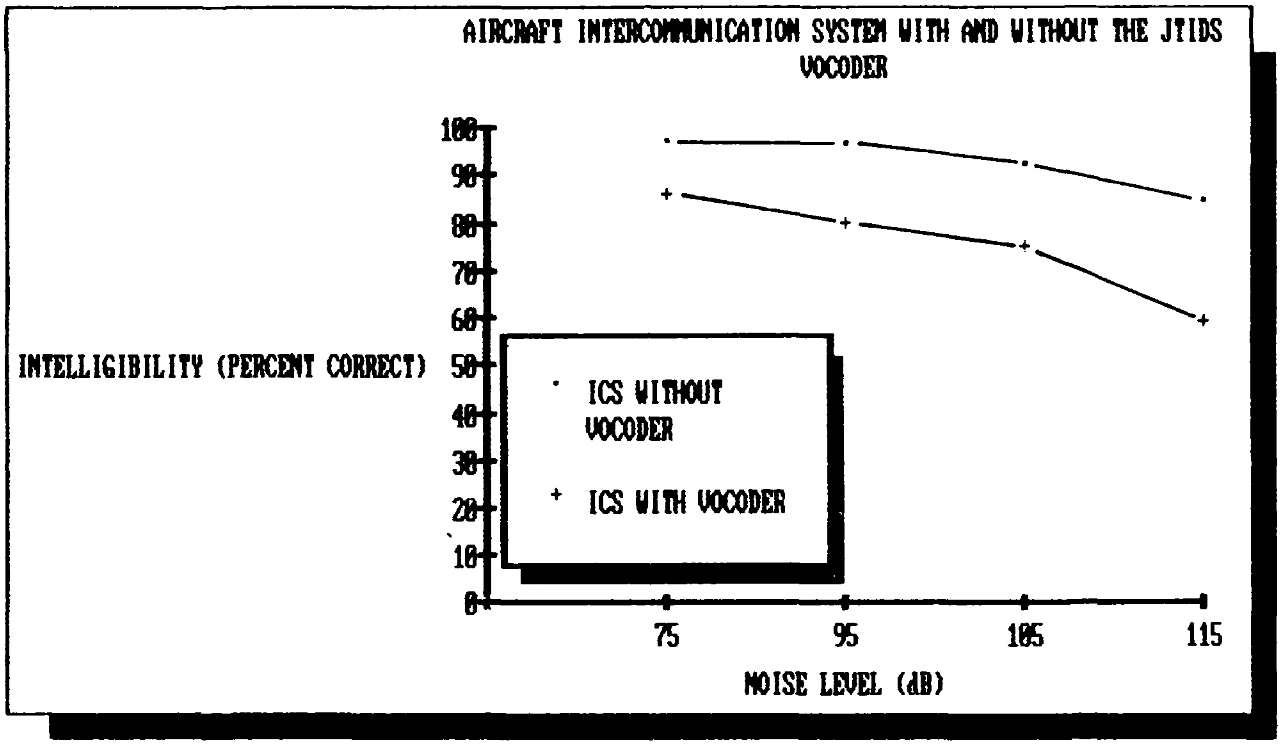


FIGURE 2. ILLUSTRATION OF THE REDUCTION IN VOICE COMMUNICATIONS INTELLIGIBILITY WHEN THE JTIDS VOCODER IS ADDED TO THE COMMUNICATIONS SYSTEM

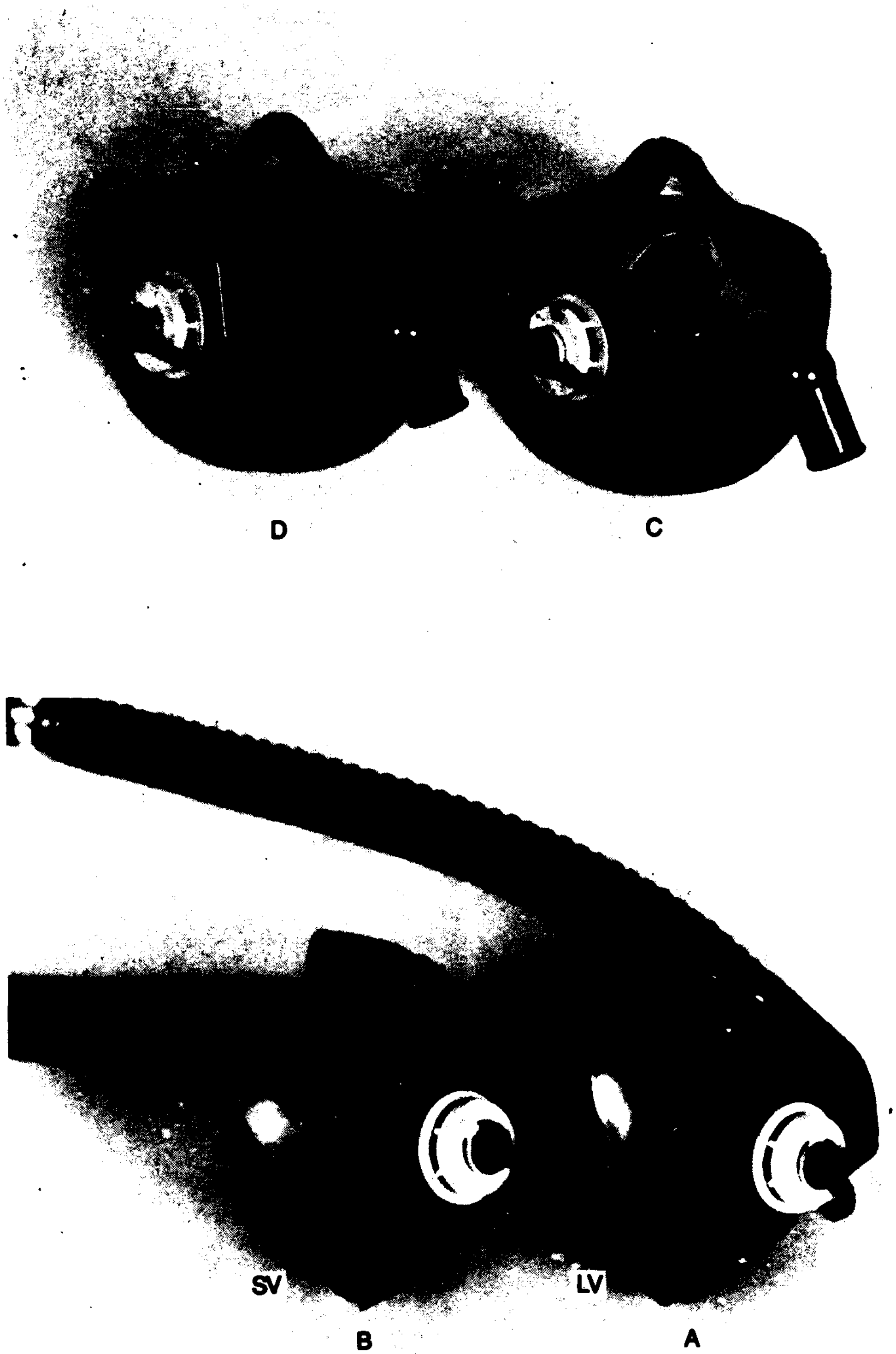


FIGURE 3. PHOTOGRAPHS OF THE OXYGENS MASKS WHICH WERE FABRICATED WITH (1) INTERNAL VOLUMES THAT WERE LARGER AND SMALLER THAN THE STANDARD MBU-12/P MASK AND (2) THE RESPIRATION VALVES RELOCATED TO THE RIGHT AND LEFT OF THE MICROPHONE

FIGURE 4. INTERNAL VIEW OF THE INSPIRATION AND EXPIRATION VALVES POSITIONED TO EITHER SIDE OF THE MICROPHONE

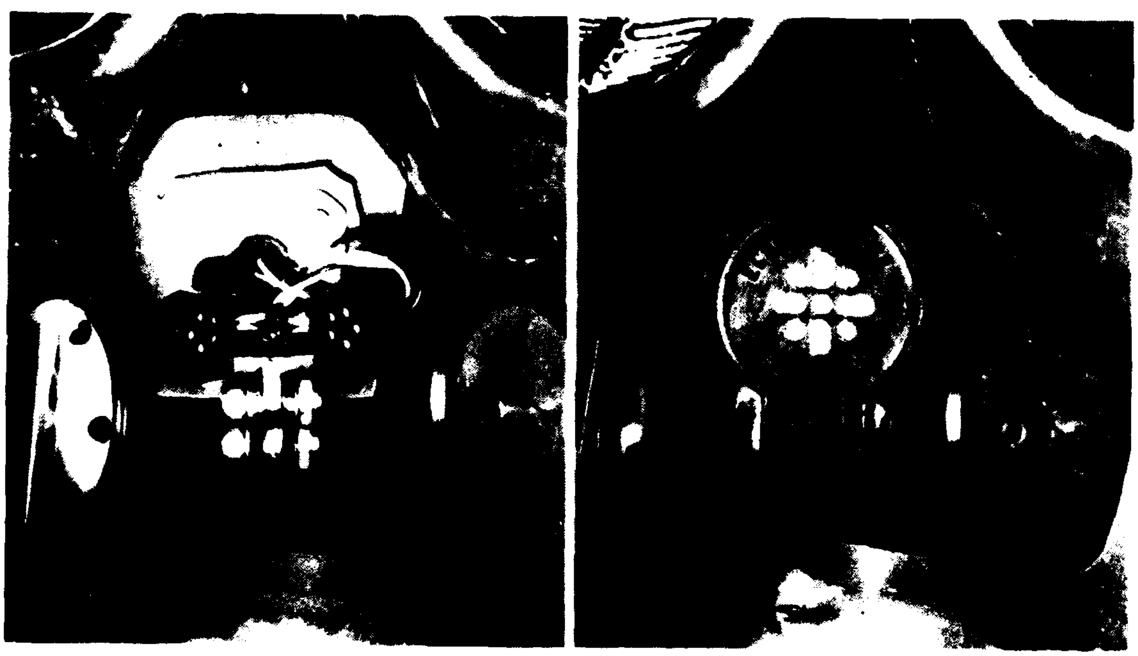
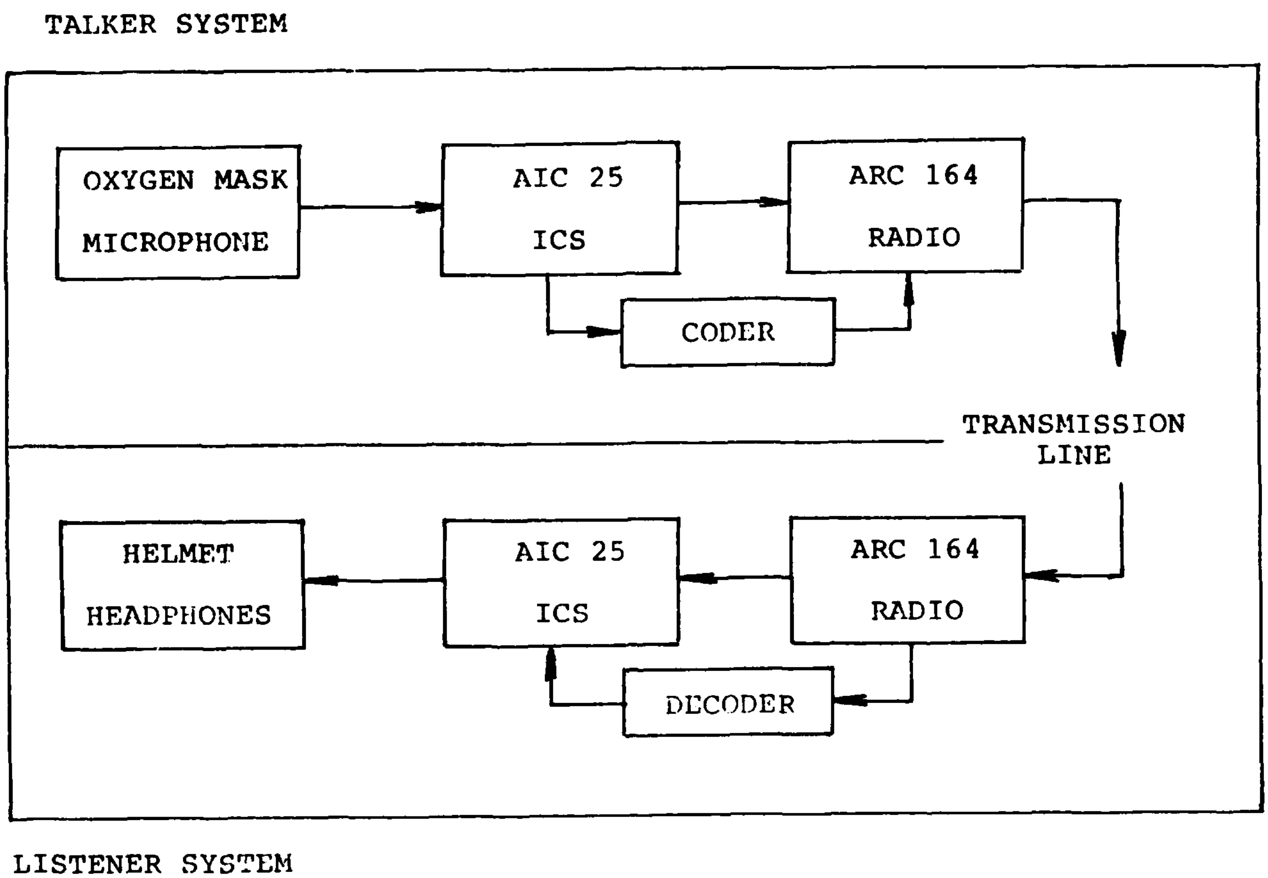


FIGURE 5. PHOTOGRAPH OF THE NOISE CANCELLING ARRAY MICROPHONE ON THE LEFT AND THE STANDARD M-101 MICROPHONE ON THE RIGHT AS MOUNTED INSIDE THE OXYGEN MASK

FIGURE 6. BASIC COMPONENTS OF THE VOICE COMMUNICATIONS SYSTEM IN THE SERIES OF RESEARCH STUDIES DESCRIBED IN THIS REPORT



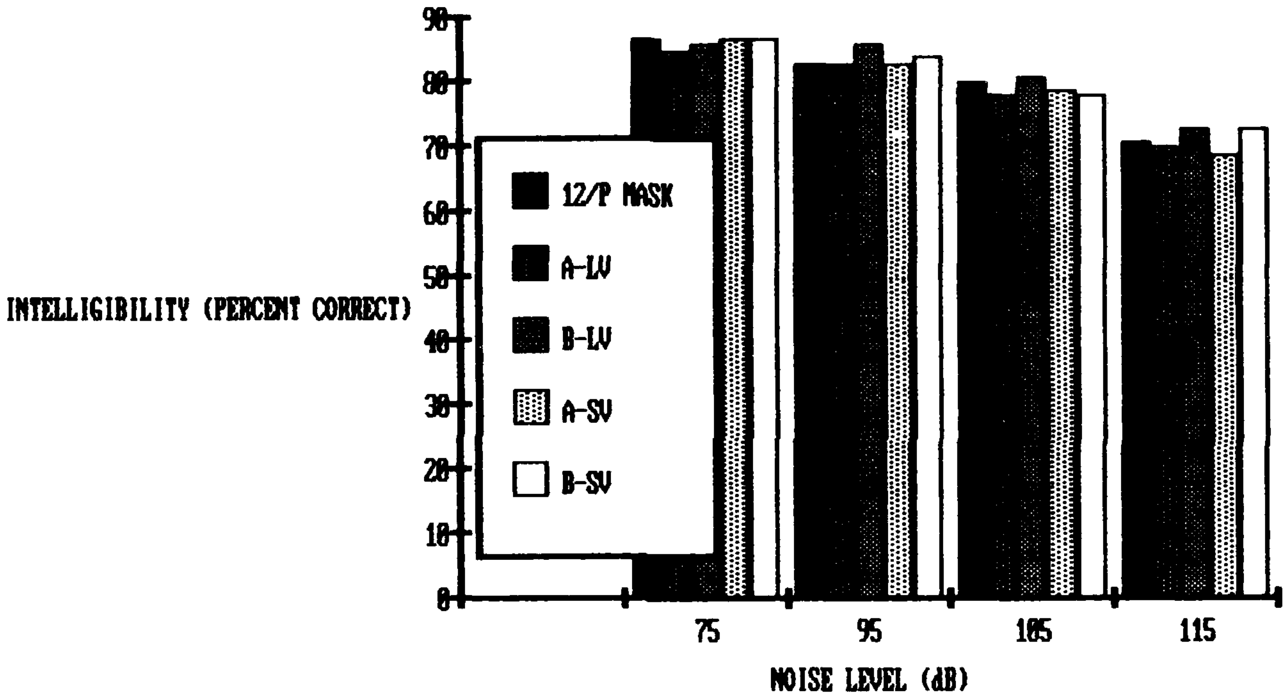
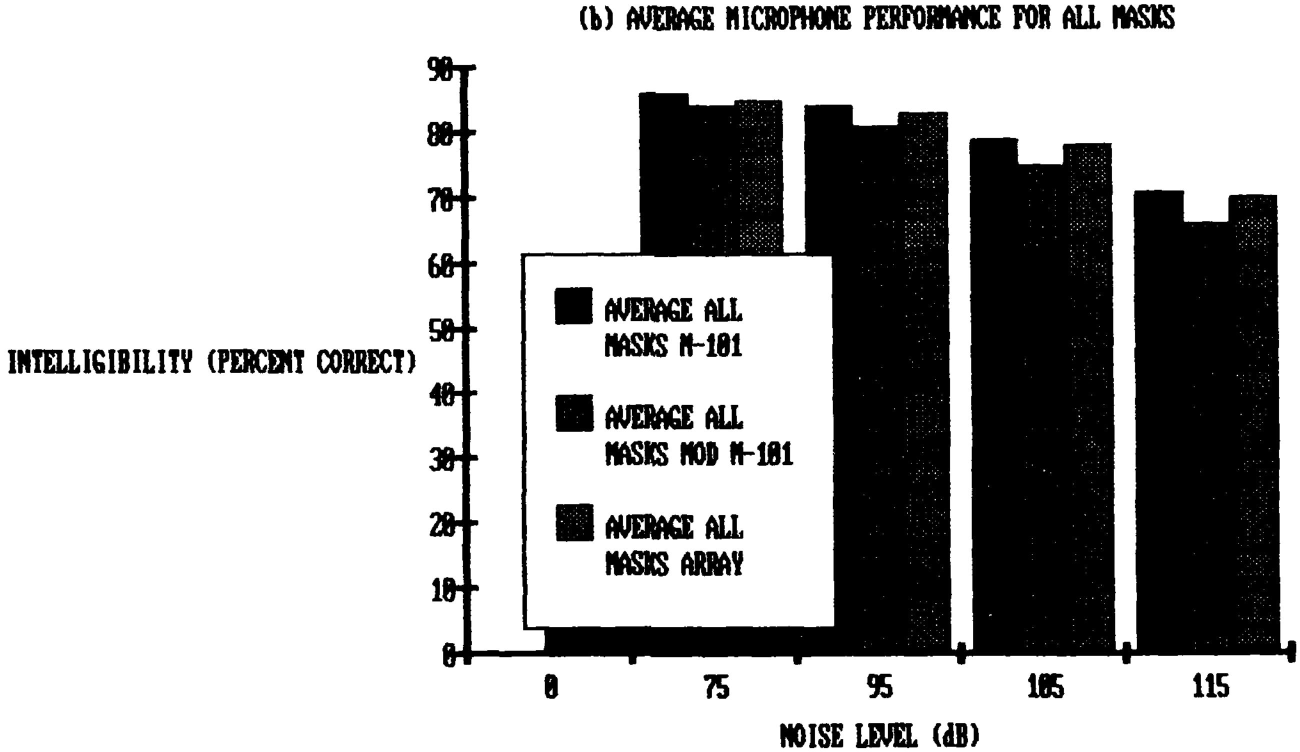


FIGURE 7. RELATIVE INTELLIGIBILITY OF EACH OF THE FIVE OXYGEN MASKS WHEN EQUIPPED WITH THE M-101 MICROPHONE



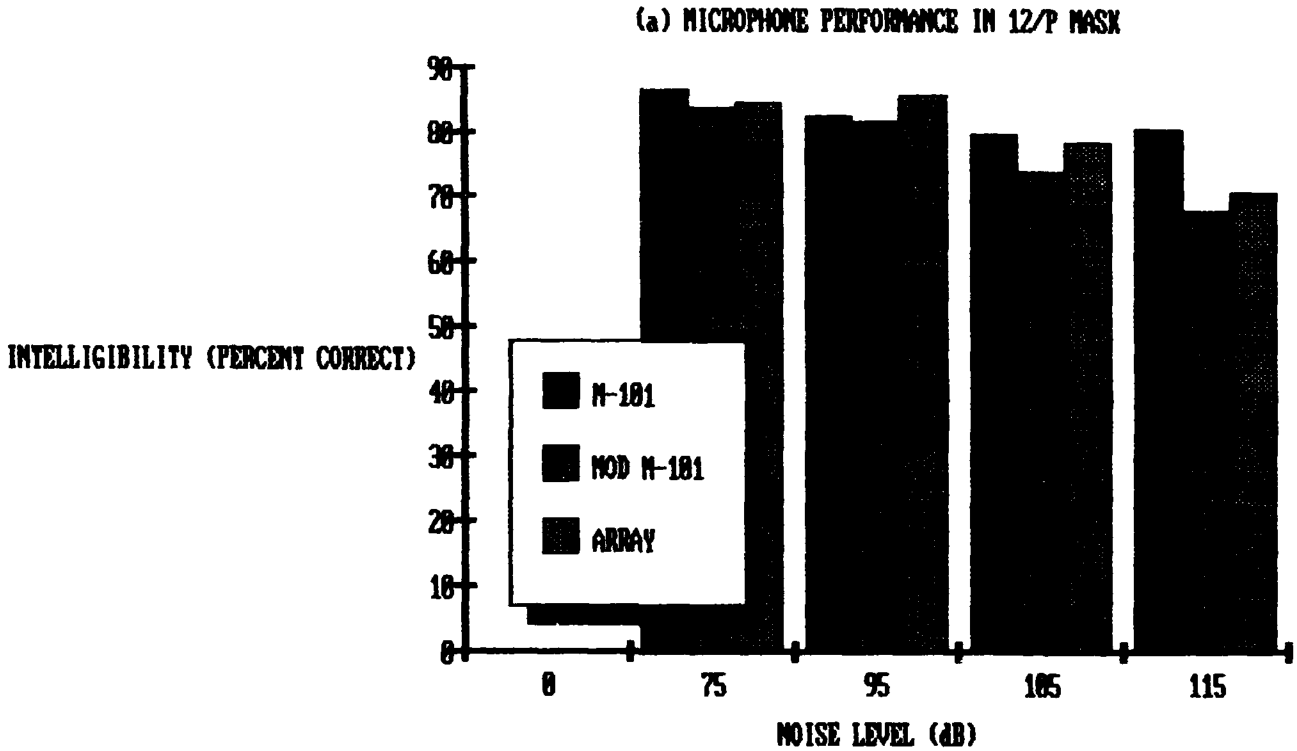


FIGURE 8. RELATIVE INTELLIGIBILITY OF THE THREE MICROPHONES WHEN MOUNTED IN THE MBU-12/P MASK AND WHEN AVERAGED ACROSS ALL MASKS

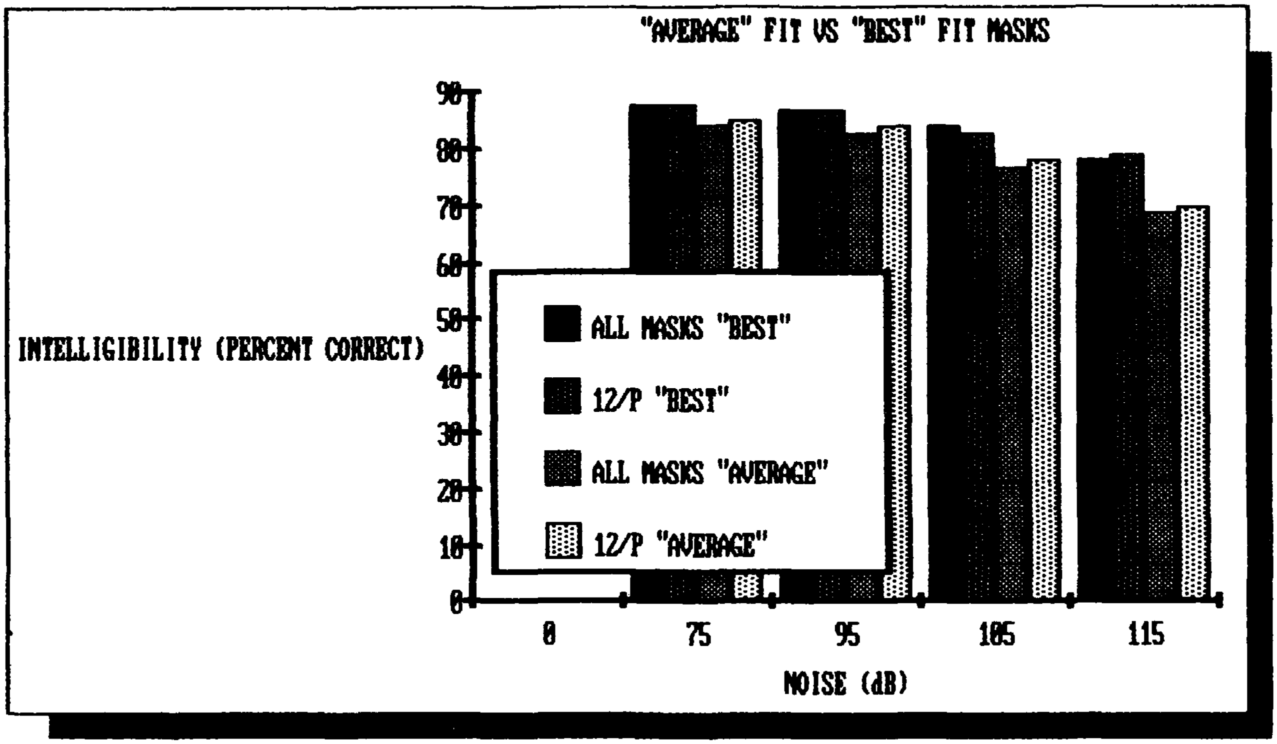


FIGURE 9. ILLUSTRATION OF THE REDUCTION IN INTELLIGIBILITY THAT MAY BE EXPERIENCED WHEN THE FIT OF THE OXYGEN MASK IS LESS THAN A "BEST" FIT

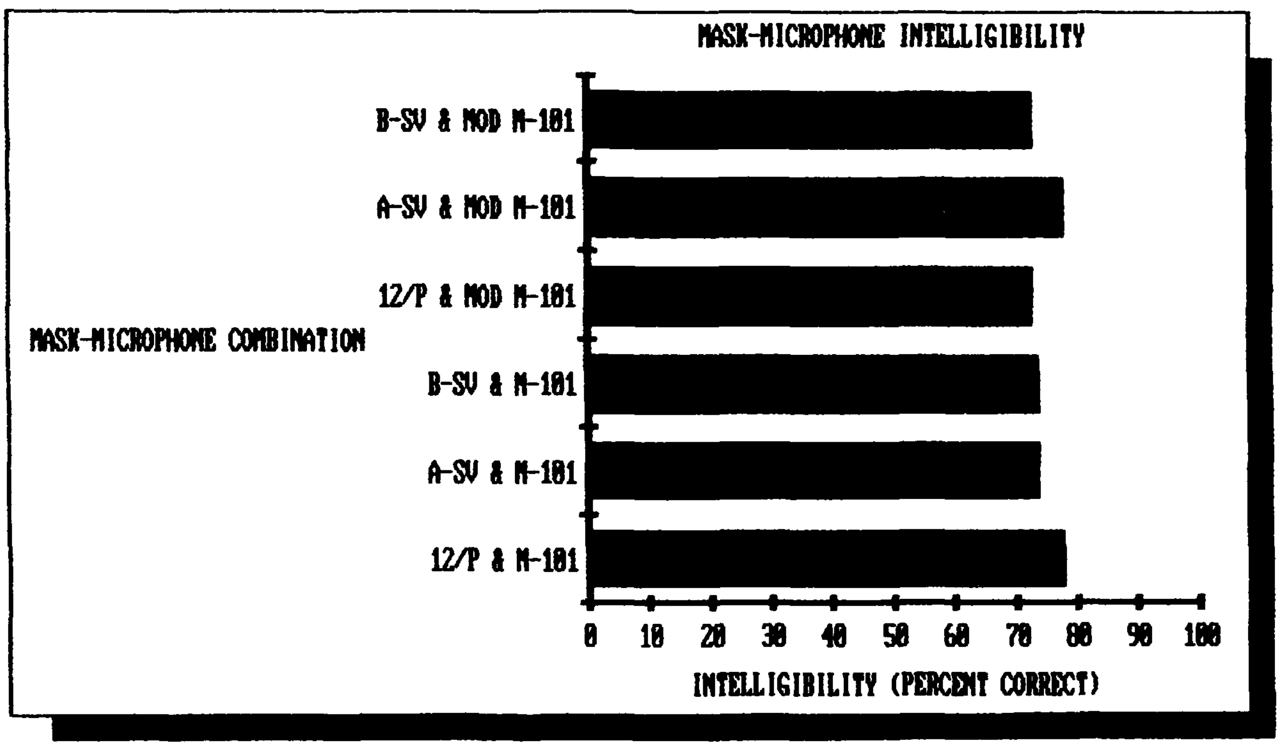


FIGURE 10. MAIN EFFECTS MEANS: RELATIVE INTELLIGIBILITY OF THE VARIOUS MASK-MICROPHONE COMBINATIONS COLLAPSED ACROSS NOISE CONDITION

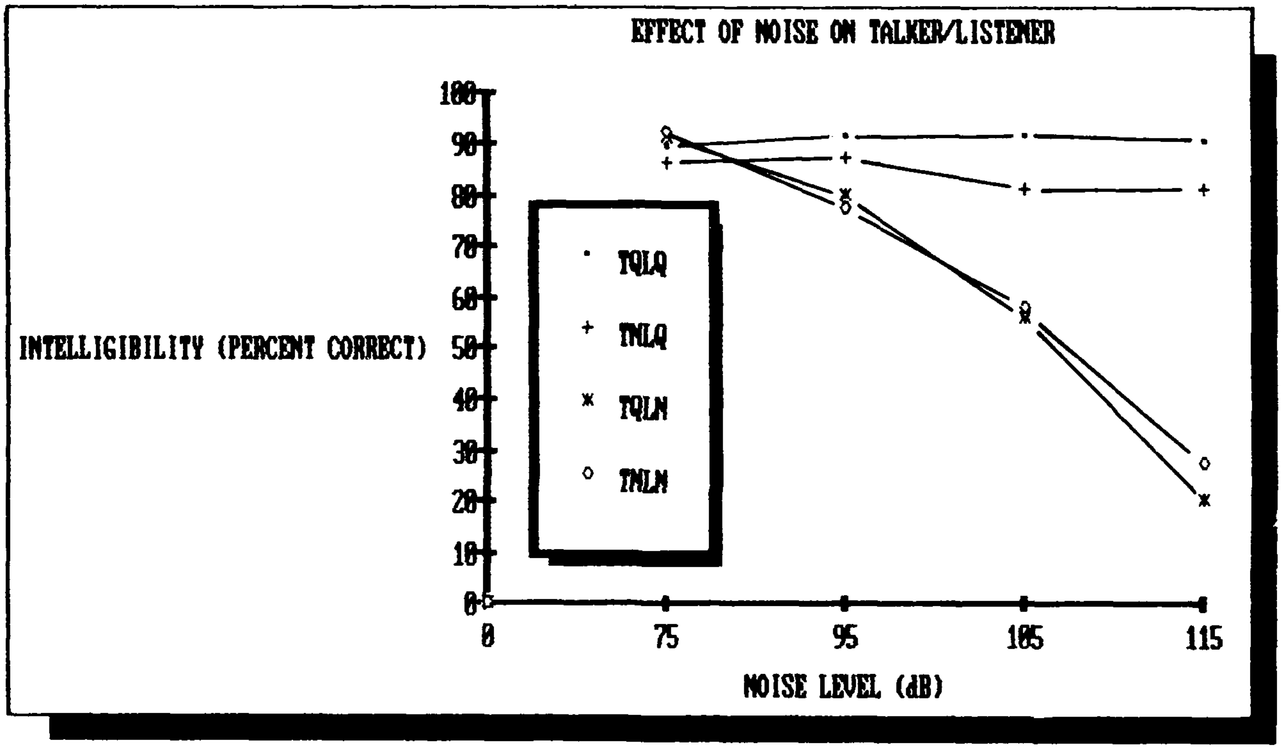


FIGURE 11. ILLUSTRATION OF THE RELATIVE EFFECTS OF THE NOISE ON TALKERS AND LISTENERS WHEN THEY ARE IN QUIET OR THE VARIOUS NOISE CONDITIONS

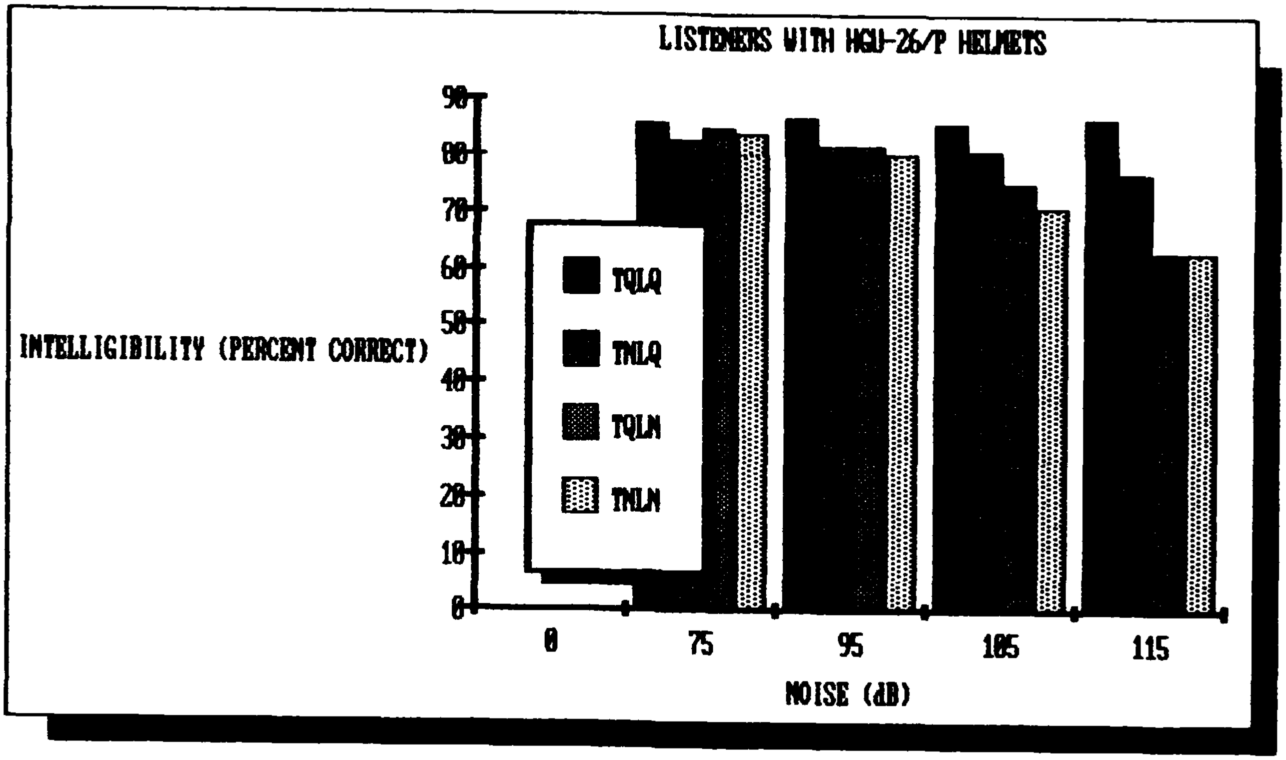


FIGURE 12. INTELLIGIBILITY OF TALKERS/LISTENERS IN NOISE/QUIET WHILE WEARING THE HGU-26/P FLIGHT HELMET

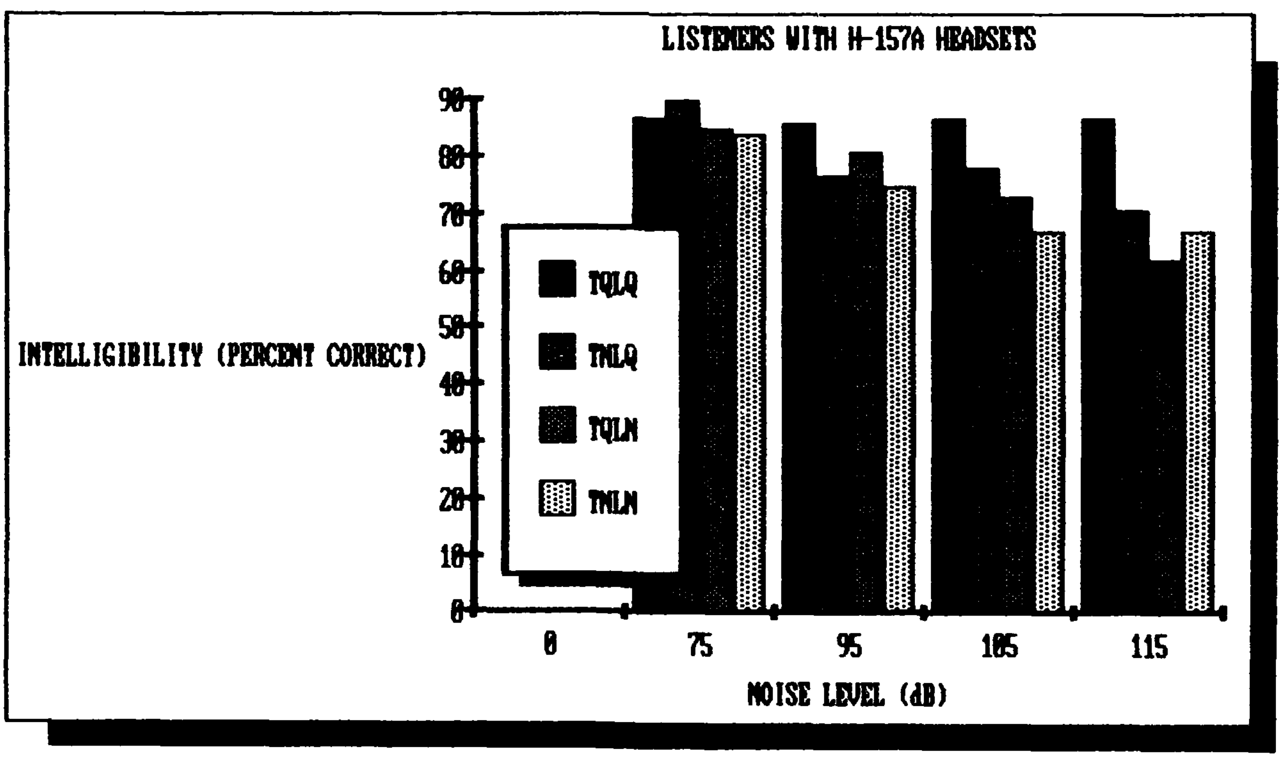


FIGURE 13. INTELLIGIBILITY OF TALKERS/LISTENERS IN NOISE/QUIET WHILE WEARING THE H-157A COMMUNICATIONS HEADSET

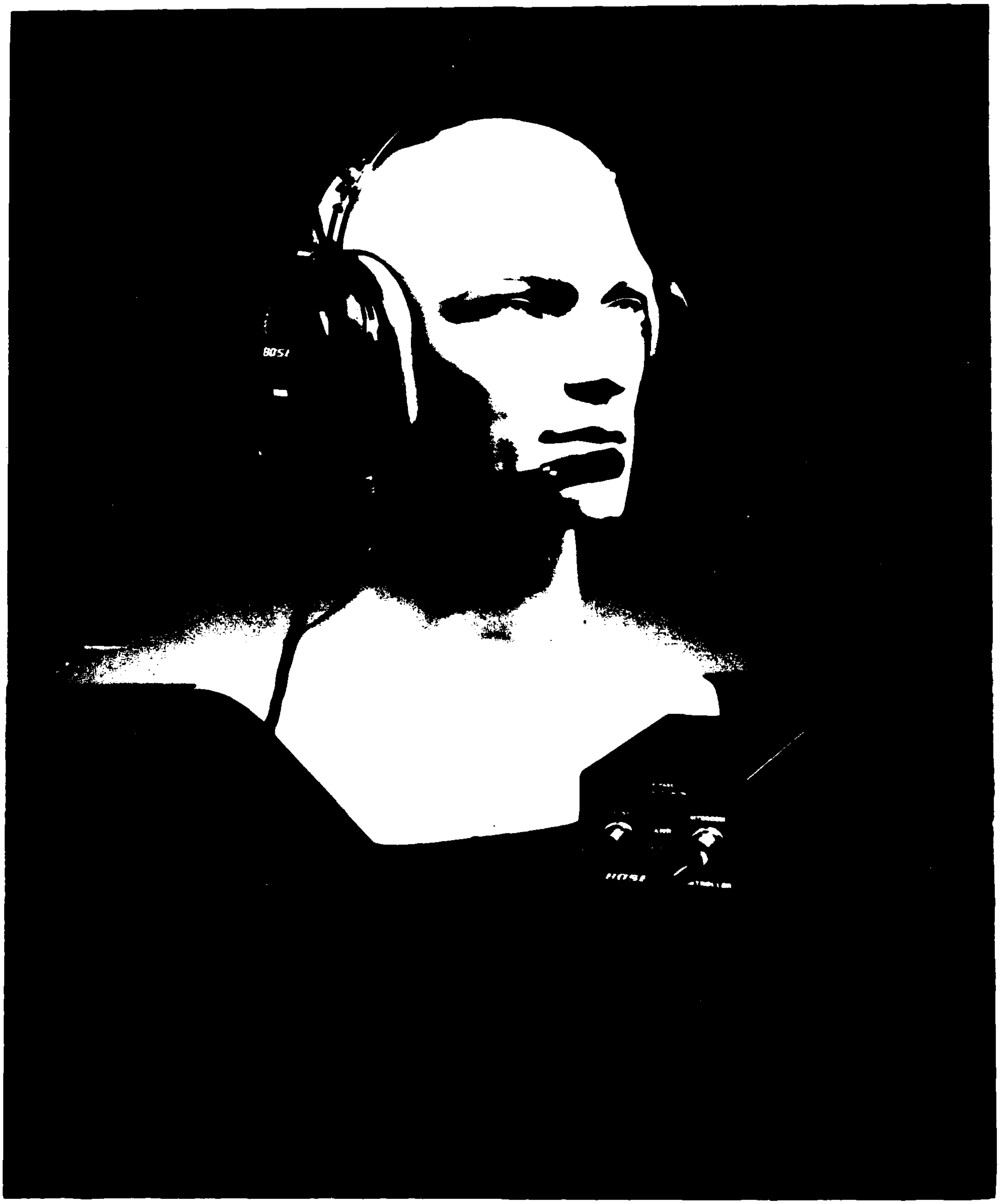


FIGURE 14. PHOTOGRAPH OF THE ACTIVE NOISE REDUCTION HEADSET SYSTEM

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